Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 4 (2022) 54–58

Journal of the Nigerian Society of Physical Sciences

Current Understanding of the Equatorial $E \times B$ Drift velocities in the African Sector: A Short Review

B. O. Adebesin[a,b,c,*], J. O. Adeniyi[a,b], I. A. Adimula[1], S. J. Adebiyi[a,b], S. O. Ikubanni[a,b], B. J. Adekoya[e]

[a] *Climate Action SDG 13 Group (Space Weather and Environment), Landmark University, Nigeria.*
[b] *Department of Physical Sciences, Landmark University, P.M.B 1001, Omu-Aran, Kwara State, Nigeria.*
[c] *Landmark University Centre for Research, Innovation and Discoveries (LUCRID), Nigeria.*
[d] *Department of Physics, University of Ilorin, Ilorin, Nigeria*
[e] *Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria*

Abstract

A short review of the pattern and morphology of the equatorial plasma drift velocities, particularly during the evening-time Pre-reversal enhancement (PRE) period in the African region had been presented. The seasonal PRE peak values across some locations in the West-African region were considered and compared with other sectors of the world. While most plasma drift observations in the African region were calculated from ionosonde measurements, the observations from other sectors involved direct measurement from satellite and the Incoherent Scatter Radar (ISR) observations. The importance of the PRE in ionospheric electrodynamics was highlighted, the better in the use of either the virtual or real heights of the F-layer in inferring vertical drift velocities were enumerated, revealing the strengths and weakness of each method. The general observations revealed that PRE peak magnitude is commonly weaker in the African region in comparison with the American/Peruvian and Indian sectors, seasonal and solar activity dependent, and could be higher during either magnetic quiet or disturbed activity than when both magnetic activity conditions are combined. The first work to present a regional PRE model around the African equatorial ionization anomaly region (Adebesin et al model) was mentioned. The relevance of the $E \times B$ drift in quantifying the daytime equatorial electrojet (EEJ) current was also discussed.

DOI:10.46481/jnsps.2021.327

Keywords: Vertical E x B Drift; Ionosphere, Plasma; Pre-reversal enhancement (PRE); African sector.

Article History :
Received: 31 July 2021
Accepted for publication: 04 February 2022
Published: 28 February 2022

Communicated by: O. J. Abimbola

1. Introduction

Equatorial vertical plasma drifts (Vp) explain the extent in terms of speed to which the ionospheric F-layer is moving vertically with respect to time. Vp plays a significant factor in describing and specifying many ionospheric models across the globe. It has also been found to be a significant factor in the manifestation of plasma bubbles and Equatorial Spread-F [1, 2, 3, 4] through the action of the evening-time Pre-reversal enhancement (PRE) activity. The PRE is the evening-time enhanced E x B drifts driven by the eastward electric field., and consequently lifts the ionosphere. The lifting interrupts the ionospheric density stability through the Rayleigh-Taylor mechanism. Vertical drifts had also been useful in the description of electron density response to solar eclipses, thus making the E x B drift an essential factor for ionospheric F2-layer redistribution during eclipse period [5]. The vertical

---

[*] Corresponding author tel. no: +234(0)8058051253
Email address: `adebesin.olufemi@lmu.edu.ng` (B. O. Adebesin)

drift velocities had been widely investigated in most sectors of the world including the Peruvian/American sector [6], and Indian sector [7, 8, 9], with little done in the African sector [10, 11, 12, 13, 14, 15].

The space-borne drift measurements through the use of the Incoherent Scatter Radar (ISR) have been well documented over Jicamarca and Millstone Hill and had been the major source of data for modelling ionospheric vertical plasma drift [16]. Data from the Jicamarca ISR and AEE satellite had been employed by [16] to find a first global empirical model for different solar activity conditions and seasons in the F-region, and subsequently injected into the IRI-2007 model. Other empirical models of repute include [17] - using ionosonde observations, [18] and [19] - obtained from ROCSAT-1 measurements, and [20] - from CHAMP satellite. All of these models and many more are predicted/forecasted outside the African sector. The first work to report modelling of the vertical plasma drift velocity in the African region, to the best knowledge of the authors, is the work of [14]. The Adebesin et al model used ground-based ionosonde data observations from Ouagadougou (Geographic lat. $12.4°N$, long. $358.6°E$ and Geomagnetic lat. $0.59°N$, long. $71.5°E$) spanning 1966-1998. The model was used in inferring a regional empirical model between the evening-time drift and the solar activity index. The model presents a strong potential for obtaining Vp magnitude around the evening/nighttime period, especially in the African equatorial ionization anomaly (EIA) region. The mathematical relation that describes the model as a function of the solar activity condition is given by the expression:

$$PRE = 0.158R_Z + 1.495 \tag{1}$$

While satellite and ISR measurements had been widely used in the investigation of the E X B drift in the other sectors of the world, the ground-based ionosonde/digisonde had been the major source of data acquisition for inferring drift pattern in the African sector. The contribution of real-time ionospheric measurements from ionosondes/digisondes are useful parameters in space weather study and forecasting [21]. The estimation of the vertical plasma drift from ground-based ionosonde measurements in the African sector had been achieved majorly by either computing the time rate of change of the F2-layer height of the peak electron density - $d(hmF2)/dt$, or by that of the virtual height of reflection - $d(h'F)/dt$ [13, 22, 23, 24]. The limitation inherent in the description of Vp using ground-based measurement is well documented in [12]. Consequently, a review of both the quantitative and qualitative characteristics of previous works done on ionospheric drift pattern in the equatorial African sector will add to our understanding on its morphology when compared with other sectors of the world. From this point forward, all observations reported are in the equatorial African sector, except otherwise specified.

2. Variations in drift pattern obtained from Ground-based ionosonde/digisonde real height and virtual height measurements

Observations involving inferring vertical plasma drift from both the height of the peak electron density (hmF2) and virtual height of the F-layer ($h'F$) methods are well established. Argument on the best Vp inferring parameter between the two ($h'F$ and hmF2) is a continuous scientific debate. However, works that describe both methods in a single paper are scarce, even from other sectors. [15] describes the morphology of Vp obtained from each method of measurement ($d(hmF2)/dt$) and $d(h'F)/dt$) using digisonde data obtained from Ilorin (Geographic $8.5°N$, $4.5°E$) in the West African region during a year of low sunspot activity. For better interpretation, the result was compared with those obtained from ISR observations (which serves as the reference drift condition) spanning the same study period. They reported a PRE highest magnitude around 19 LT for the entire seasons with hmF2-Vp while that of $h'F - Vp$ also recorded the maximum at 19 LT (except for December solstice and September equinox, which peaked at 18 LT). The nighttime downward reversals peak values range from -2 to -14 m/s and -4 to -14 m/s respectively for the $h'F - Vp$ and $hmF2 - Vp$ observations. Further, the PRE peak magnitude across the entire seasons ranges from $4-14$, $3-14$ and $2-14$ m/s respectively for the ISR-Vp, hmF2-Vp and $h'F - Vp$. A correlation percentage of above 83% was recorded for the ISR-Vp versus hmF2-Vp and ISR-Vp versus $h'F - Vp$ pairs of observations between 16-20LT during equinoxes, but lower for solstices (¡ 40%).

Table 1 depicts the intra-hour bin time correlation values for the ground-based ionosonde versus ISR observations revealing the correlation magnitudes (R) expressed in percentage, between the pairs for different time intervals. While the PRE magnitude of $h'F - Vp$ compares well with ISR-Vp during equinoxes, that of hmF2-Vp is equitable to ISR-Vp during solstices. Bearing in mind that both methodologies are governed by the same mechanism at night, it was concluded that any of the two can be used as long as the 300 km threshold magnitude condition suggested by Bertoni [25] and [26] is fulfilled, else chemical modification may be necessary. See also [27] for more discussion on this condition.

3. Seasonal variations in the PRE peak magnitude across equatorial stations in Africa and comparison with other sectors.

A summary of the evening-time maximum PRE magnitude of the vertical plasma drift velocity across various stations in Africa (and other sectors), including the type of methodology involved in inferring the drift, as well as solar activity conditions are presented in Table 2. The Table revealed that during the combined magnetic disturbed and quiet conditions in the African region, the maximum PRE magnitude for June solstice, December solstice, and Equinox respectively generally spans around 7.6-12.0 m/s, 8.0-15.2 m/s and 8.0-20.0 m/s (from the PRE magnitudes presented by [14, 15, 28]). It was observed that the maximum peak limit for each of these seasons during

Table 1: Seasonal correlation coefficient (R) between ISR-Vp versus $h'F - Vp$ and ISR-Vp versus hmF2-Vp for different nighttime interval periods (** are periods without data for the ISR observation)

Time interval	Parameter	Mar. equinox	Sept. Equinox	Jun. Solstice	Dec. Solstice
16-19 LT	ISR-Vp vs $h'F - Vp$	83%	**	99%	33%
	ISR-Vp vs hmF2-Vp	99%	**	78%	88%
19-21 LT	ISR-Vp vs $h'F - Vp$	88%	87%	68%	93%
	ISR-Vp vs hmF2-Vp	94%	90%	86%	99%
21-06 LT	ISR-Vp vs $h'F - Vp$	67%	53%	87%	76%
	ISR-Vp vs hmF2-Vp	72%	29%	82%	58%

this condition of combined quiet and disturbed magnetic condition (12, 15, and 20 m/s) can be boosted either during only magnetic disturbed or quiet condition as shown from the PRE peak values reported by [10, 29, 30]. Besides, PRE peak values are mostly higher during magnetic quiet period relative to disturbed activities. [31] had submitted that quiet magnetic activities compare reasonably with the thremospheric ground state owning to small rate of atomic oxygen (O^+) during the time. The separate magnetic quiet or disturbed during June solstice is associated with high PRE peak values comparable to the values during equinoxes (i.e., [31]). Further, PRE peak values are lesser during low solar activities when compared with high solar activity magnitudes, establishing solar dependence of PRE.

This study also revealed that on the average, the PRE peak value obtained from $h'F$ is higher than that inferred from hmF2 for the entire seasons from the work of [15]. This higher value associated with PRE obtained from $h'F$ measurements may be connected to the disappearance of both the D- and E-layer of the ionospheric region at night, thereby leaving the F-layer active. During this period, the F-layer bottomside time rate of change is more accurate. Conversely for the F-layer peak height (hmF2), the exact height may not be obtained accurately owning to merging of all layers during its measurement.

It has been observed by [18] that PRE peak magnitude in the American region is higher than those obtained from other sectors including the African sector. This statement was confirmed from Table 2. The Table showed that the PRE peak magnitude during the equinoxes is higher in the American sector in comparison to the African region (with the exception of the one by [15]; using ISR observations during low sunspot condition). The situation is same for the December solstice period. It is also worth noting that the evening time PRE peak presents inverse linear relationship with the electron ionization gradient parameter defined by the height rate of change of the F2-layer peak electron density, dN/dh [35].

4. Measuring the Electrojet current from ground-based vertical drift measurements

Of the diverse relevance of the equatorial vertical plasma drift velocities, its practical relation to physical events like the equatorial ionization anomaly, fountain effect, and Spread-F are outstanding as these phenomena can alter the reliability of communication and navigation systems. The equatorial Spread-F phenomena originates within the E-layer current system, in form of an intense ionospheric daytime eastward current, and narrowed within 3° dip latitude; often referred to as the equatorial electrojet (EEJ). Several studies have been done on the electrojet strength using different approaches, methodologies, and tools. The electrojet current is triggered by local intensified ionospheric currents as well as physical structures flowing at the dip equator with high current strengths at daytime period leading to variation in solar quiet (Sq) signature. While the relationship between the measurement of the difference between the horizontal magnetic field component at an equatorial and an off-equatorial station, at daytime, had been used to obtain the equatorial vertical plasma drift [36], the quantification of the daytime EEJ current with the plasma drift in the American and Indian longitudes had also been established [7, 36, 37]. While [38] and [39] had presented novel observation of the EEJ current in the African sector, the relationship between electrojet current and the E x B drift were not considered. Based on the authenticated outcome of E x B drift velocities - EEJ relationship around daytime hours obtained by [40] and [7] for the American and Indian sectors respectively, [24] attempted same in the African region, using data from Ilorin, being the first of such study in the African sector.

MAGDAS and ionosonde inferred measurements at Ilorin were used during solar minima year. The results obtained revealed that a maximum morning time representative parameter defined by the expression $E_w = [d(\Delta H)/dt]_{max}$ at daytime, representing the east-west electric field in electrojet current matches considerably with the $E \times B$ drift, and therefore can serve as a representation/proxy parameter in depicting the magnitude of the vertical drift in the morning hour. The linear correlation between the two parameters (E_w and plasma drift) is 0.94 and observed during low solar activity. [7] recorded a correlation coefficient of 0.66 for a high solar activity condition in the Indian sector, while [36] reported a correlation value of 0.87 at the American sector. The good relationship between the two parameters is because an increase in the E_w magnitude implies an intensification of the EIA, which subsequently reduces the plasma density around the equator; thereby rapidly increasing the plasma density along the crest regions. The plasma density reduction over the magnetic equator further diminishes the effect of ion drag on neutrals, thus enhancing the zonal wind prior to sunset. These processes create a large eastward electric field raising the amplitude of the post-sunset $E \times B$ drift of the F-layer.

Table 2: Seasonal PRE peak magnitudes in the African and other sectors

Source	Data Instrument / Source	Sector/Station	Solar activity	Equinox (m/s)		Solstices (m/s)	
				March	September	June	December
[28]	Ionosonde / $h'F$ median	Africa (Korhogo)	Descending phase of solar cycle (SC) 22	12.6	8.7	8.0	12.0
		Africa (Ouagadougou)		15.2	11.0	7.4	10.9
		Africa (Dakar)		10.0	7.7	7.9	8.0
[29]	Ionosonde/ $h'F$ mean	Africa	Moderate	40.1	30.1	31.2	30.2
[14]	Ionosonde / $h'F$ mean	Africa (Ouagadougou)	SC 20. 1966-1976	18.6	16.3	10.7	10.6
		Africa (Ouagadougou)	SC 21. 1976-1986	19.5	19.0	11.3	13.2
		Africa (Ouagadougou)	SC 22. 1986-1996	19.1	18.0	10.1	14.7
		Africa (Ouagadougou)	1966-1998	18.1	15.8	12.1	12.9
[15]	Digisonde / $h'F$ mean	Africa (Ilorin)	Low	12.7	12.8	2.2	13.3
	Digisonde / $hmF2$ mean	Africa (Ilorin)	Low	9.2	3.8	0.3	8.0
[11]	Ionosonde / hmF2 mean	Africa (Ouagadougou)	High	17.1[b]		16.1	14.1
[30]	Ionosonde / $h'F2$ median	Africa (Ibadan)	High	33.6[b]		26.9	26.7
[10]	Ionosonde / $h'F$ mean	Africa (Ibadan) Quiet	High	33.0	28.0	42.0	28.0
		Africa (Ibadan) Disturbed	Low	[a]	18.0	23.0	23.0
[15]	ISR	Peruvian (Jicamarca)	Low	13.6	9.6	[a]	6.4
[32]	ISR	Peruvian (Jicamarca)	High	32.0[b]		14.0	28.1
[16]	ISR and AE-E Satellite	Peruvian (Jicamarca)	1968-1992, 1977-1979	45.0[b]		35.0	38.1
[33]	HF Sounder	Indian (Kodaikanal)	High	26.4[b]		25.0	20.8
[34]	VHF Radar	Peruvian (Jicamarca)	High	50.0[b]		17.0	38.1

[a] insignificant magnitude
[b] Equinoctial average values

5. Conclusion and Recommendation

A review of the morphology of vertical plasma drift in the African region was presented. Reviewed literatures capturing drift velocities in the West-African region including Ibadan (Nigeria), Ilorin (Nigeria), Ouagadougou (Burkina Faso), Dakar (Senegal), and Korhogo (Cote d'Ivorie), were used, and compared with other observations especially during the PRE period in the Peruvian/American sector. The observations include periods of high-, moderate-, and low-solar activities, as well as 11-year and descending phases of solar activities. It also includes different magnetic activity conditions. The various observations point to the fact that the magnitude of the drift pattern obtained from ground-based ionosondes in the African region is lesser than those obtained from other sectors. However, most ionospheric satellite observational studies have revealed exciting longitudinal pattern in equatorial region electrodynamics. The peak of these variations in terms of irregularities is severe in the African sector owning to the better alignment between the geomagnetic and geodetic equators, whereas in the American/Peruvian sector, the geomagnetic equator dips, presenting fairly huge disparity between the geomagnetic and geodetic equator. This could have been responsible for the large excursion in the PRE. It has been observed by Fejer et al. (2008) that PRE peak magnitude in the American region is higher than those obtained from other sectors including the African sector. This statement was confirmed from Table 2. The Table showed that the PRE peak magnitude during the equinoxes is higher in the American sector in comparison to the African region (with the exception of the one by Adebesin et al., 2015b; using ISR observations during low sunspot condition). The situation is same for the December solstice period. drift pattern observed with the Jicamarca ISR drift observation in relation to those inferred from ionosonde measurements in the African region. Consequently, having an ISR equipment in Africa will further increase our understanding of the drift morphology in explaining the uniqueness of ionospheric irregularities in the African sector as well as the possible mechanism that initiates such unique structures.

References

[1] C. R. Martinis, M. J. Mendillo & J. Aarons, "Toward a synthesis of equatorial spread F onset and suppression during geomagnetic storms", J. Geophys. Res. **110** (2005) 7306.

[2] J. Park, M. Noja, C. Stolle, & H. Luhr, "The ionospheric bubble index deduced from magnetic field and plasma observations onboard swarm", Earth, Planets and Space **65** (2013) 1333. https://doi.org/10.5047/eps.2013.08.005

[3] C. S. Huang, de la Beaujardiere, O., P. A. Roddy, D. E. Hunton, J. Y. Liu, & S. P. Chen, "Occurrence probability and amplitude of equatorial ionospheric irregularities associated with plasma bubbles during low and moderate solar activities (2008-2012)", Journal of Geophysical Research: Space Physics **119** (2014) 1186. https://doi.org/10.1002/2013JA019212

[4] D. Okoh, B. Rabiu, K. Shiokawa, Y. Otsuka, B. Segun, E. Falayi, S. Onwuneme, R. Kaka, "First study on the occurrence frequency of equatorial plasma bubbles over West Africa using an all-sky airglow imager and GNSS receivers", Journal of Geophysical Research: Space Physics **122** (2017) 12430. https://doi.org/10.1002/2017JA024602

[5] B. J. Adekoya, V. U. Chukwuma, & B. W. Reinisch, "Ionospheric vertical plasma drift and electron density response during total solar eclipses at equatorial/low latitude", Journal of Geophysical Research - Space Physics **120** (2015) 8066.

[6] D. N. Anderson, A. Anghel, K. Yumoto, M. Ishitsuka, & E. Kudeki, "Estimating Daytime, Vertical E x B Drift velocities in the Equatorial F region Using Ground-based Magnetometer Observations", GRL, **29**(2002), doi: 10.1029/ 2001GL014562.

[7] V. C. Sreeja, V. Devasia, Sudha Ravindran, & T. K. Pant, "Observational evidence for the plausible linkage of Equatorial Electrojet (EEJ) electric field variations with the post sunset F-region electrodynamics", Ann. Geophys. **27** (2009) 4229.

[8] J. T. Uemoto, Maruyama, S. Saito, M. Ishii and R. Yushimura, "Relationship between pre-sunset electrojet strength, PRE and ESF onset", Ann Geophys. **28** (2010) 449.

[9] L. Liu, J. Yang, H. Le, Y. Chen, W. Wan, & C. C. Lee, "Comparative study of the equatorial ionosphere over Jicamarca during recent two solar minima", J. Geophys. Res. **117** (2012) A01315, doi: 10.1029/2011JA017215.

[10] O. S. Oyekola, & C. O. Oluwafemi, "Solar and geomagnetic trends of equatorial evening and nighttime F region vertical ion drift" J. Geophys. Res. **113** (2008) A12318.

[11] O. S. Oyekola & L. B. Kolawole, "Equatorial vertical E x B drift velocities inferred from ionosonde measurements over Ouagadougou and the IRI-2007 vertical ion drift model", Adv. Space Res. **46** (2010) 604.

[12] J. O. Adeniyi, B. O. Adebesin, I. A. Adimula O. A. Oladipo, A. O. Olawepo, S. O. Ikubanni, & B. W. Reinisch, "Comparison between African Equatorial Station Ground-based inferred vertical E x B drift, Jicamarca direct measured drift, and IRI model" Advances in Space Research **54** (2014a) 1629. doi:10.1016/j.asr.2014.06.0 14.

[13] B. O. Adebesin, J. O. Adeniyi I. A. Adimula, & B. W. Reinisch, "Low latitude Nighttime Ionospheric vertical E x B drifts at African Region. Advances in Space Research. **52** (2013a), 2226. doi: 10.1016/j.asr.2013.09.033.

[14] B. O. Adebesin, A. B. Rabiu, J. O. Adeniyi, & C. Amory-Mazaudier, "Nighttime morphology of vertical plasma drifts at Ouagadougou during different seasons and phases of sunspot cycles 20-22", J. Geophys. Res. Space Physics **120** (2015a) 10020, doi:10.1002/2015JA021737.

[15] B. O. Adebesin, J. O. Adeniyi, I. A. Adimula O. A. Oladipo A.O. Olawepo & B. W. Reinisch, "Comparative Analysis of Nocturnal Vertical Plasma Drift velocities inferred from Ground based ionosonde measurements of hmF2 and h'F", Journal of Atmospheric and Solar-Terrestrial Physics. **122** (2015b) 97. doi:10.1016/j.jastp.2014.11.0 07.

[16] L. Scherliess & B. G. Fejer, "Radar and satellite global equatorial F-region vertical drift model", J. Geophys. Res. **104** (1999) 6829.

[17] I. S. Batista, R. de Medeiros, M. Abdu, J. de Souza, G. Bailey, & E. de Paula, "Equatorial ionospheric vertical plasma drift model over the Brazilian region", J. Geophys. Res. **101** (1996) 10887.

[18] B. G. Fejer, J. W. Jesen & S. Su, "Quiet time equatorial F-region vertical plasma drift model derived from ROCSAT-1 observations", J. Geophys. Res. **113** (2008) A05304. http://dx.doi.org/10.1029/2007JA012801

[19] H. Kil, R. A. Heelis, L .J. Paxton, S.J. Oh, "Formation of a plasma depletion shell in the equatorial ionosphere" J. Geophys. Res. **114** (2009) 1. http://dx.doi.org/10.1029/2009JA014369

[20] H. Luhr, M. Rother, K. Hausler, P. Alken, S. Maus, "The influence of non-migrating tides on the longitudinal variation of the equatorial electrojet", J. Geophys. Res. **113** (2008) A08313. http://dx.doi.org/10.1029/2008JA013064

[21] B. W. Reinisch, & I. A. Galkin, "Global Ionospheric Radio Observatory (GIRO)", Earth Planets Space. **63** (2011) 377. doi:10.5047/eps.2011.03.001.

[22] O. K. Obrou, D. Bilitza, J. O. Adeniyi, S. M. Radicella, "Equatorial F2-layer peak height and correlation with vertical ion drift and M(3000)F2", Adv. Space Res. **31** (2003) 513.

[23] B. O. Adebesin, J. O. Adeniyi, I. A. Adimula, B. W. Reinisch, "Equatorial vertical plasma drift velocities and electron densities inferred from ground-based ionosonde measurements during low solar activity", J. Atmos. Sol. Terr. Phys. **97** (2013b) 58. http://dx.doi.org/10.1016/j.jastp.2013.02.010

[24] J. O. Adeniyi, I. A. Adimula, B. O. Adebesin, B.W. Reinisch, O. A. Oladipo, A. O. Olawepo, K. Yumoto, "Quantifying the EEJ current with Ground-based ionosonde inferred vertical ExB drifts in the morning hours over Ilorin, West Africa", Acta Geophys. **62** (2015b) 656. http://dx.doi.org/10.2478/s11600-014-0202-0.

[25] F. Bertoni, I. S. Batista, M. A. Abdu, B. W. Reinisch, & E. A. Kherani, "A comparison of Ionospheric vertical drift velocities measured by Digisonde and Incoherent Scater Radar at the magnetic equator", J. Atmosph. Solar Terr. Phys. **68** (2006) 669. http://dx.doi.org/10.1016/j.jastp.2006.01.002.

[26] J. A. Bittencourt, M. A. Abdu, "A theoretical comparison between apparent and real vertical ionization drift velocities in the equatorial F-region", J. Geophys. Res. **86** (1981) 2451.

[27] B. O. Adebesin, "The 300km threshold value for vertical drifts inferred from F-region heights: Past observations, Present developments, and future works. NRIAG", Journal of Astronomy and Geophysics **5** (2016) 30. doi: 10.1016/j.nrjag.2016.04.001.

[28] B. O. Adebesin, A. B. Rabiu, O. S. Bolaji, J. O. Adeniyi, & C. Amory-Mazaudier, "Ionospheric Climatology at Africa EIA trough stations during Descending Phase of Sunspot Cycle 22", Journal of Atmos. and Solar-Terrestrial Physics **172** (2018a) 83, doi: 10.1016/j.jastp. 2018.03.009.

[29] F. O. Grodji, V. Doumbia, K. Boka, C. Amory-Mazaudier, Y. Cohen, & R. Fleury, "Estimating some parameters of the equatorial ionosphere electrodynamics from ionosonde data in West Africa", Adv. Space Res. **59** (2017) 311. https://doi.org/10.1016/j.asr.2016.09.004.

[30] O. S. Oyekola, "Equatorial F-region vertical ion drifts during quiet solar maximum", Advances in Space Research. **43** (2009) 1950.

[31] A. V. Mikhailov, V. H. Depuev, & A. H. Depueva, "Synchronous NmF2 and NmE daytime variations as a key to the mechanism of quiet-time F2-layer disturbances", Ann. Geophys. **25** (2007) 483.

[32] C. C. Lee, J. Y. Liu, B. W. Reinisch, W.S. Chen, & F. D. Chu, "The effects of the pre-reversal drift, the EIA asymmetry, and magnetic activity on the equatorial spread F during solar maximum", Annales Geophysicae **23** (2005) 745.

[33] K. B. Ramesh & J. H. Sastri, "Solar cycle and seasonal variations in F region vertical drifts over Kodaikanal, India", Ann. Geophys. **13** (1995) 633.

[34] B. G. Fejer, E. R. de Paula, S. A. Gonzales, & R. F. Woodman, "Average vertical and zonal F-region plasma drifts over Jicamarca", J. Geophys. Res. **96** (1991) 13901.

[35] B. O. Adebesin, J. O. Adeniyi, O. A. Oladipo, A. O. Olawepo, A. O. & I. A. Adimula, "Quantitative Characteristics of Equatorial Ionization Gradient Above 150 km at Low Solar Activity", Radio Science **53** (2018b) 948. https://doi.org/10.1029/2018RS006560.

[36] D. E. Anderson, Araujo-Pradere & L. Scherliess, "Comparing daytime, equatorial E x B drift velocities and TOPEX/TEC observations associated with the 4-cell, non-migrating tidal structure", Ann. Geophys. **27** (2009) 2861.

[37] A. P. Eduardo, N. D. Anderson, M. Fedrizzi & R. Stoneback, "Quantifying the day-time, equatorial E x B drift velocities at the boundaries of the 4-cell tidal structure using C/NOFS' CINDI observations", The International Beacon Satellite Symposium BSS2010 P. Doherty, M. HernÃ¡ndez-Pajares, J.M. Juan, J. Sanz & A. Aragon-Angel (Eds) Campus Nord UPC, Barcelona. (2010)

[38] I. A. Adimula, A. B. Rabiu, Y. Yumoto, & the MAGDAS Group, "Geomagnetic field variations from some equatorial electrojet stations", Sun and Geosphere 1819-0839 **6** (2011) 39.

[39] O. S. Bolaji, A. B. Rabiu, I. A. Adimula, J. O. Adeniyi & K. Yumoto, "Inter-hemispheric Trans- equatorial Field-aligned Currents Deduced from MAGDAS at Equatorial Zone", Space Research Journal **4** (2011) 12,.DOI:10.3923/srj.2011.12.22.

[40] D. Anderson, A. Anghel, J. L. Chau, & O. Veliz, "Daytime vertical E x B drift velocities inferred from ground-based magnetometer observations at low latitudes", Space Weather **2** (2004) S11001, doi: 10.1029/2004 SW000095.